The International DORIS Service (IDS) – Recent developments in preparation for ITRF2013

Pascal Willis[1,2], Frank G. Lemoine[3], Guilhem Moreaux[4], Laurent Soudarin[5], Pascale Ferrage[6], John Ries[7], Michiel Otten[8], Jerome Saunier[9], Carey Noll[10], Richard Biancale[11], Brian Luzum[12]

[1]IGN, Direction de la Recherche et de l'Enseignement, Saint-Mandé, France, pascal.willis@ign.fr

[2]IPGP, Planetologie et Sciences spatiales, Paris, France, willis@ipgp.fr

[3]GSFC, Greenbelt, MD, USA, frank.g.lemoine@nasa.gov

[4]CLS, Toulouse, France, gmoreaux@cls.fr

[5]CLS, Toulouse, France, lsoudarin@cls.fr

[6]CNES, Toulouse, France, pascale.ferrage@cnes.fr

[7]U. Texas, Center for Space Research, Austin, TX, USA, ries@csr.utexas.edu

[8]ESA, Darmstaadt, Germany, michiel.otten@esa.int

[9]IGN, Service de Geodesie et de Nivellement, Saint-Mande, France, jerome.saunier@ign.fr

[10]GSFC, CDDIS, Greenbelt, MD, USA, carey.e.noll@nasa.gov,

[11]CNES, Toulouse, France, richard.biancale@cnes.fr

[12]USNO, Washington DC, USA, brian.luzum@usno.navy.mil

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Abstract. The International DORIS Service (IDS) was created in 2003 under the umbrella of the International Association of Geodesy (IAG) to foster scientific research related to the French DORIS tracking system and to deliver scientific products, mostly related to the International Earth rotation and Reference systems Service (IERS). We first present some general background related to the DORIS system (current and planned satellites, current tracking network and expected evolution) and to the general IDS organization (from Data Centers, Analysis Centers and Combination Center). Then, we discuss some of the steps recently taken to prepare the IDS submission to ITRF2013 (combined weekly time series based on individual solutions from several Analysis Centers). In particular, recent results obtained from the Analysis Centers and the Combination Center show that improvements can still be made when updating physical models of some DORIS satellites, such as Envisat, Cryosat-2 or Jason-2. The DORIS contribution to ITRF2013 should also benefit from the larger number of ground observations collected by the last generation of DGXX receivers (first instrument being onboard Jason-2 satellite). In particular for polar motion, sub-milliarcsecond accuracy seems now to be achievable. Weekly station positioning internal consistency also seems to be improved with a larger DORIS constellation.

1 Introduction

Following a preliminary Pilot Project (Tavernier et al. (2002)), an International DORIS Service (IDS) was created in 2003 to foster international scientific cooperation for geodesy and geophysics (Willis et al. (2010)). DORIS is an acronym for Doppler Orbitography and Radiopositioning Integrated by Satellite. The goal of this paper is to present the first steps taken by the IDS groups in preparation for the next ITRF2013, to discuss new DORIS results, future improvements and possible limitations. We will present recent improvements related to the DORIS technique (evolution of the satellite constellation and ground infrastructure). Then, after a brief description of the current IDS organization, we will detail the current IDS plans in preparation for ITRF2013. Finally, we will provide a few examples showing areas where further improvements are still required.

2 DORIS ground and satellite infrastructure

Unlike Global Navigation Satellite Systems (GNSS), the number of DORIS satellites changes with time as the main application of this system is Precise Orbit Determination (POD) for real-time (Jayles et al. (2010)) or post-processing applications (Cerri et al. (2010); Lemoine et al., (2010)) and not time and positioning on the Earth. As of September 2013, data from five DORIS satellites can be used for geodesy and geophysics through the IDS Data Centers, including the recent Chinese HY-2A satellite and the Indian Saral satellite, both launched for altimetry.

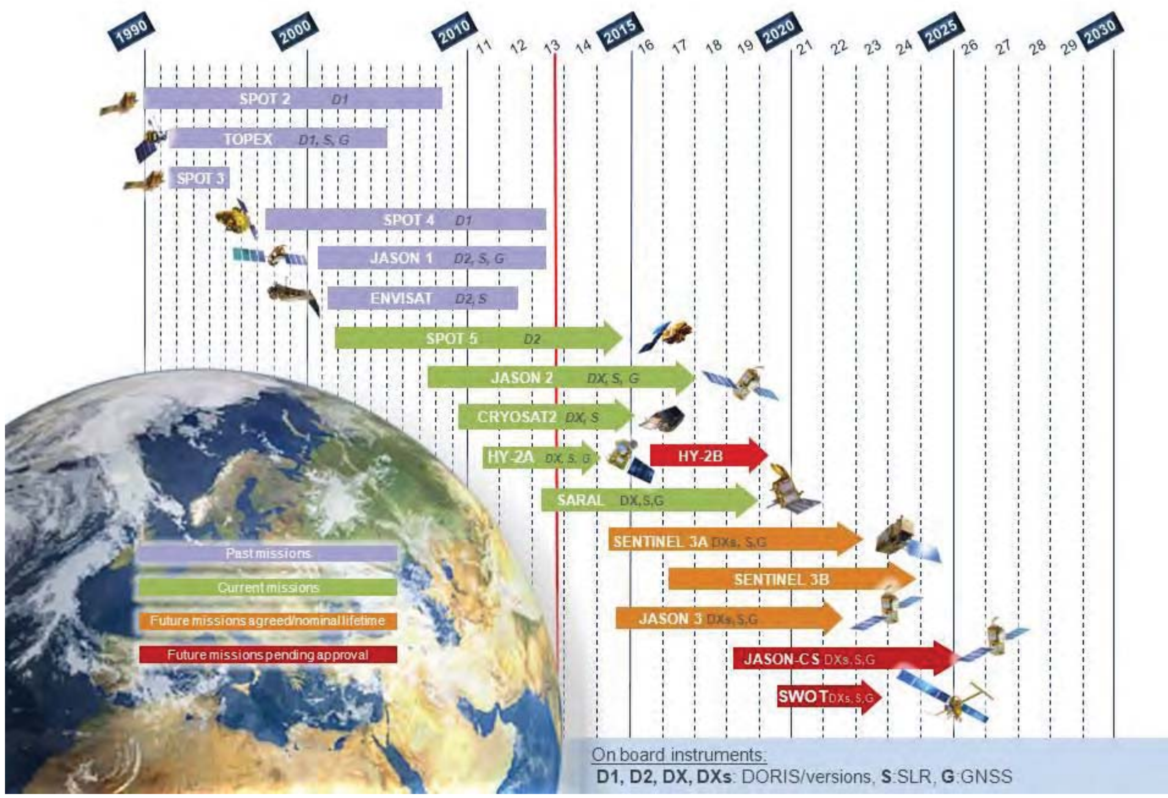

Figure 1 Current DORIS satellite constellation (September 2013)

Figure 1 shows that more DORIS satellites should also be launched in the next few years. According to CNES, the DORIS system could maintain operations at least until 2026 (Ferrage, personal communication), if not 2030. It must also be noted that the most recent DORIS satellites now include onboard DGXX receivers, allowing a more robust tracking of the ground stations, thanks to their new multi-channel technology (Auriol and Tourain, 2010). Up to seven

DORIS ground tracking stations can be tracked simultaneously by each of the new satellites (instead of previously only one for SPOT-2,-3, -4 and TOPEX/Poseidon and later two for SPOT-5, Jason-1, and Envisat).

Since 1993, the DORIS ground tracking network has remained rather stable with time (Fagard, 2006) with 50 to 60 operating stations. As displayed in Figure 2, this network is geographically well distributed and also includes a large number of sites co-located with other space techniques such as Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and GNSS, contributing and enhancing the development of the ITRF and its applications (Altamimi et al., (2005); Altamimi and Collilieux (2010)). For the ground equipment, only two types of DORIS antennae have been used. The Alcatel antennae, used initially, have now been all replaced with the Starec generation.

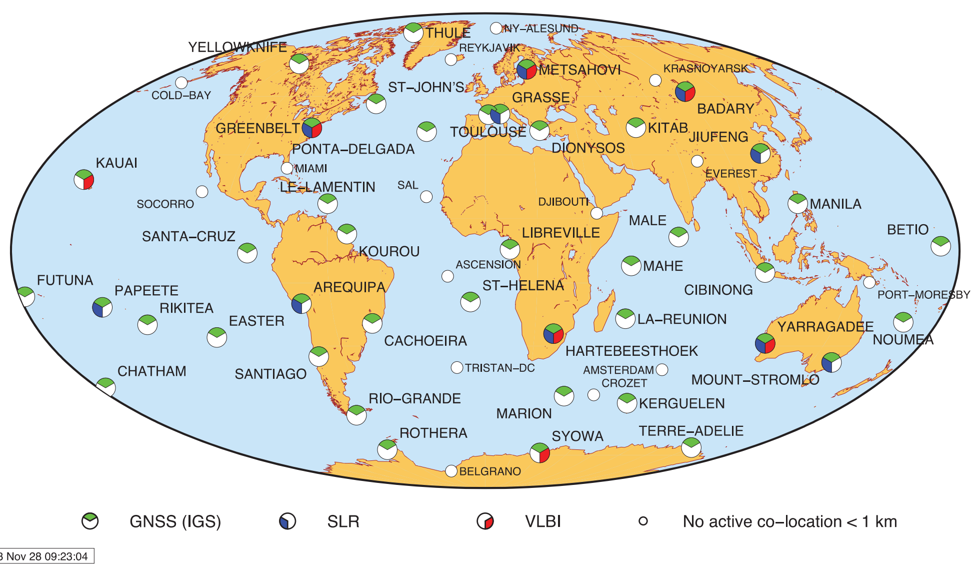

Figure 2 Current DORIS tracking network and co-location with other geodetic space techniques (November 2013)

More information regarding these stations, such as the description of co-located instruments, for instance geodetic technique instruments but also absolute gravity and tide gauges, can be found in the electronic supplement of Willis et al. (2010) and also online through a GoogleEarth application developed by the IDS Central Bureau at http://ids-doris.org/network/googleearth.html).

3 International DORIS Service – Current structure and products

Like the other IAG Services, the IDS is organized as follows: several Analysis Centers (see Table 1) generating different scientific products, a Combination Center (at CLS) combining these results, two Data Centers (at NASA/CDDIS and at IGN) archiving the different DORIS data and products (Noll, 2010), a Central Bureau (CNES/CLS/IGN) providing day-to-day

operations and in particular maintaining the IDS Web site (http://ids-doris.org), and a Governing Board giving long-term directions and ensuring regular contact with other entities such as the IAG, Global Geodetic Observing System (GGOS) and the IERS.

Table 1 Past and current IDS analysis centers

Analysis Center	Acronym	Country	Software package	Current status
ESA/ESOC	ESA	Germany	NAPEOS	active
Geosciences Australia	GAU	Australia	GEODYN	past
GeoForschungsZentrum	GFZ	Germany	EPOS	proposed
NASA/GSFC	GSC	USA	GEODYN	active
Geodetic Observatory of Pecny	GOP	Czech Rep.	Bernese	active
IGN	IGN	France	GIPSY-OASIS	active
INASAN	INA	Russia	GIPSY-OASIS	active
CNES/CLS	LCA	France	GINS/DYNAMO	active

As of September 2013, six Analysis Centers (using 5 different software packages) plan to participate in the IDS combination, providing weekly time series of station positions with full covariance information in SINEX format with either normal equations or as loosely constrained solutions with full covariance information. These six individual contributions will be merged by the IDS Combination Center (Valette et al. (2010)), providing a unique DORIS time series, which would then be used by the ITRF Combination Centers (Altamimi et al. (2011); Seitz et al., (2012)) to realize the future ITRF2013 solution, in conjunction with similar combinations provided by VLBI, SLR and GNSS.

Table 2 displays the different products generated for the IDS by the Analysis Centers (ACs) and/or by the Combination Center.

Table 2 List of current IDS products (September 2013)

Product	format	Frequency delivery	from Analysis Center	from Combination Center
station coordinates	SINEX	weekly	√	√
Earth Orientation Parameters	IDS	weekly	√	√
geocenter motion	IDS	weekly	√	√
orbits	sp3	daily	√	
reference frame	SINEX	yearly	√	

DORIS can also provide other types of scientific results such as precise orbit determination, as discussed before, as well as tropospheric Zenith Total Delays (ZTDs), as recently shown by Bock et al. (2010) and Stepanek et al. (2010).

4 Plans towards ITRF2013

Almost all Analysis Centers plan to use the most recent EIGEN-6S2 gravity field (Förste et al. (2012); Rudenko et al. (submitted)), which augments a new static field with annual fits to time variable gravity coefficients derived from the GRACE mission (Tapley et al. (2004)) or from SLR data outside this period of time (Cerri et al. (2013)). As proposed for ITRF2008, solar radiation reflectivity scaling factors or improved macromodels will be used for all DORIS satellites when modeling the radiation pressure accelerations (Gobinddass et al. (2009); Le Bail

et al. (2010)) and an atmospheric drag parameter will be estimated more frequently (every 30 minutes to 8 hours, depending on the satellite altitude and on the daily values of the geomagnetic indices) (Gobinddass et al. (2010); Stepanek et al. (2010)). The implementation of the satellite attitude laws in POD software has been re-verified by some analysis centers. The periodic changes in the solar array pitch of the SPOT-5 satellite after 22 January 2008, as previously detected in Gobinddass et al. (2009) are also now explicitly accounted for, following new information available from CNES (ftp://ftp.ids-doris.org/pub/ids/satellites/DORISSatelliteModels.pdf). Problems related to some DORIS data sets were also recently corrected: timetagging for Envisat, South Atlantic Anomaly (SAA) effects on SPOT-5 oscillator (Stepanek et al. (2013)).

Some problems that were not previously detected and which affected the ITRF2008 solutions are now solved. As an example, Figure 3 shows that some DORIS Analysis Centers did not handle properly the frequency offsets between the actual frequency of the transmitted signal at 2GHz by the beacons and its nominal value (2.03625 GHZ). The error, which resulted from using standard station frequency value, was corrected by modifying the partial derivatives for bias estimation. This error mostly affected the estimated station height, introducing discontinuities in some of the AC solutions, which were consequently propagated into the combined solution as well as in the ITRF2008.

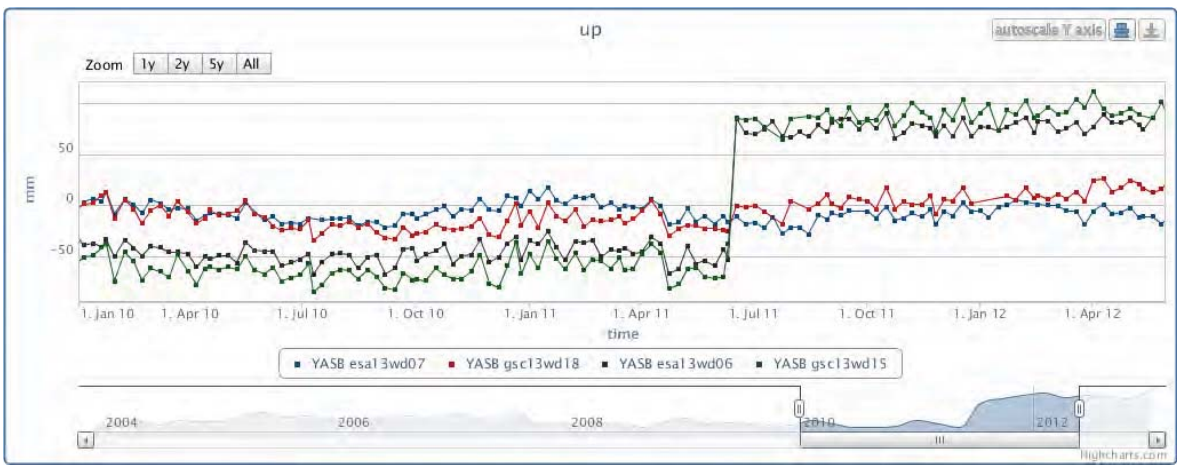

Figure 3 Time series of weekly station height determination for Yarragadee station: two solutions used for ITRF2008 and their current preliminary solutions for ITRF2013 (using Plottool). Previous esa13wd07 (in green) and gscwd06 (in black) show a clear discontinuity, coming from a data processing artifact.

As shown in Figure 3, the new solutions do not display any discontinuity related to a change in ground oscillator frequency, while the previous solutions used in preparation of ITRF2008 were affected by a large discontinuity. This problem is now solved and consequently should not affect the IDS combination, nor the future ITRF2013 solution.

5 Early results towards ITRF2013

In preparation for ITRF2013, intensive comparisons were made by all Analysis Groups under the direction of the Analysis Coordinator (Frank Lemoine). Some of the orbit comparisons for all satellites were made and some of them demonstrated deficiencies for some of the Analysis Centers. In preparation for ITRF2013, more detailed tests were also performed for some of the DORIS orbit parameters, especially the once-per-revolution (OPR) empirical accelerations, usually estimated once per day for each satellite. The magnitude of the empirical accelerations reflects the quality of the non-conservative force modeling and can be used to identify problems

in the satellite force models used in the data processing. This is important for the quality of the DORIS results as previous studies demonstrated that errors in non-conservative force models can map into errors in the geodetic results such as TZ-geocenter or the height of high latitude stations. These errors can appear with strong signals at the satellite draconitic (solar beta-prime) periods, when large values of the OPR try to mitigate deficiencies in the solar radiation pressure modeling (Willis et al. (2006)). The estimation of a cross-track empirical once-per revolution (OPR) acceleration has been a standard practice in POD analysis for altimeter satellites or by DORIS analysis centers (e.g. Le Bail et al. (2010); Lemoine et al. (2010); Zelensky et al. (2010); Cerri et al. (2010)). However, this parameter is not always well-determined and appears to weaken the DORIS coordinate solutions in certain satellites. For this reason, some ACs decided to avoid estimating the cross-track OPR as was the practice for all previous ITRF solutions (including ITRF2008).

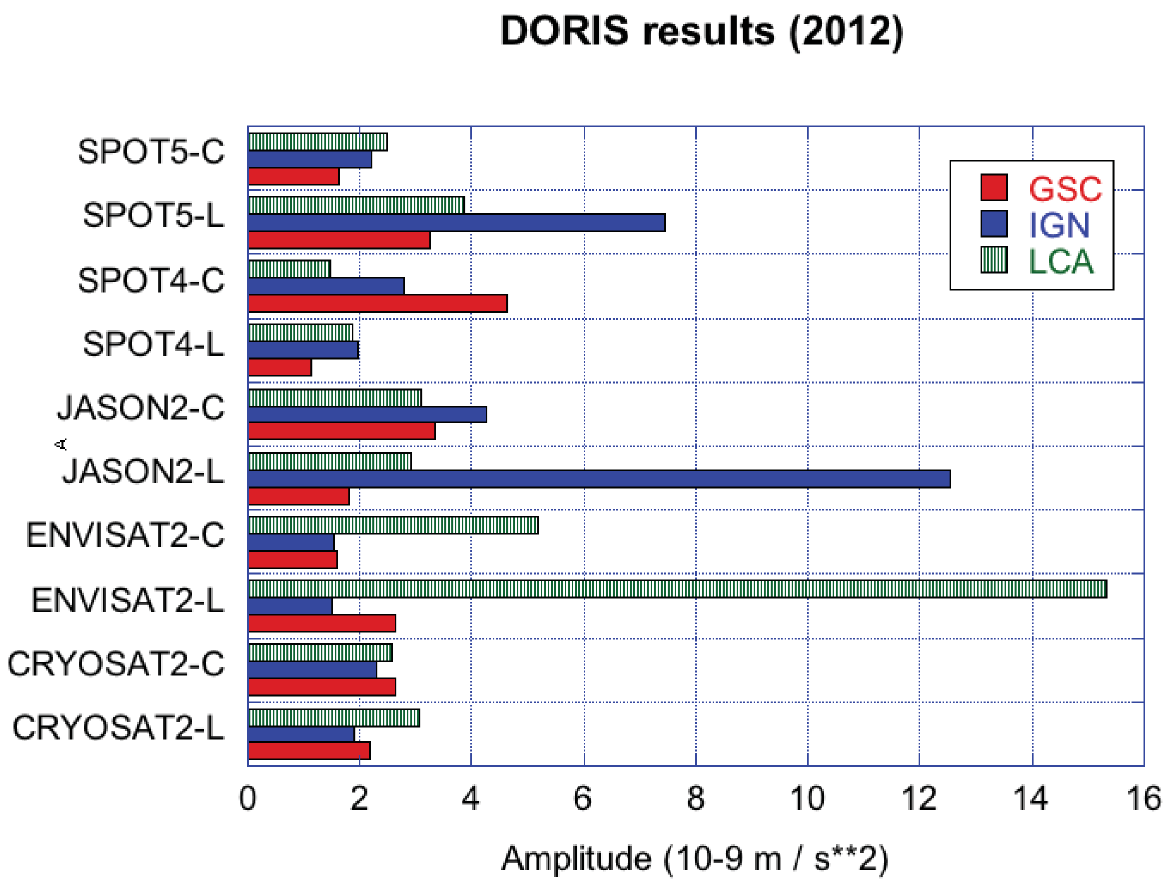

Figure 4 RMS of DORIS empirical parameters (once-per-revolution) estimated by satellite (in 2012), cross-track (C), and along-track (L).

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Figure 4 summarizes for 2012 the RMS daily amplitude of the along-track and cross-track accelerations for the DORIS satellites processed by the GSC, IGN, and LCA analysis centers. Some modeling problems are still evident in these statistics: e.g., Envisat for LCA, Jason-2 and SPOT-5 for IGN. It can also be seen that the groups that perform better for these satellites may not perform as well for other satellites. Systematic inter-comparisons of results between groups and open discussions should help to resolve such disparities in performance, allowing all groups to provide the best possible results by the end of this verification phase. Early discussions already allowed some groups to identify and to resolve modeling issues for some satellites.

However, other problems are also common to all groups and may be more difficult to solve. For example, Figure 5 shows that a significant jump can be seen in the DORIS results for Tz translation (from the combined solution) when the new Jason-2 data are introduced. A more detailed analysis showed that all groups observe this feature. This apparent discontinuity in Tz has two origins: i) From the end of the availability of DORIS on TOPEX/Poseidon (in November 2004), as Jason-1 was not included in the weekly solutions due to the sensibility of its Ultra Stable Oscillator (USO) to radiation in the SAA region, Jason-2 was the first satellite with a different orbit plane (66° of inclination compared to 98° for the rest of the DORIS constellation at that time); ii) Jason-2 is the first satellite with the so-called DORIS receiver on board that can track up to seven beacons simultaneously (compared to one for SPOT-2-4 and two for SPOT-5 and Envisat). We interpret this change – a better centering of the Tz parameter of the combination solution -- as beneficial, and thus it motivated the DORIS ACs to consider the inclusion of Jason-1 from November 2004 to July 2008. The Jason-1 DORIS data will be processed with the SAA data correction provided by Lemoine and Capdeville (2006), where the Jason-1 station data most affected by the SAA will be down-weighted or excluded from the combination.

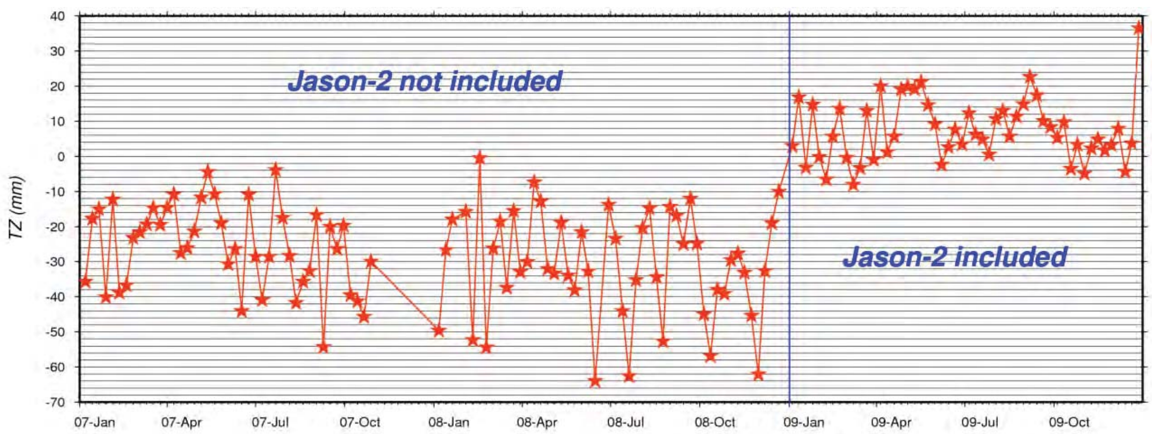

Figure 5 TZ-geocenter weekly comparisons between the preliminary IDS combined weekly solution and the ITRF2008. Vertical line in blue corresponds to a change in the DORIS constellation.

We also observe impacts on the Earth orientation parameters such as polar motion, when data from the new DORIS satellites (Jason-2, Cryosat-2, HY-2A) are added to the weekly solutions. We compare in Figure 6 the differences in the computed EOP values with the IERS C04 series (Bizouard and Gambis, 2009). The series was provided by the ESA analysis center and represents a step in the development of that analysis center's contribution to the IDS combination for ITRF2013. The largest EOP discrepancies occur prior to 2002 - before SPOT-5 and Envisat started providing data. A noticeable improvement occurs especially for the Xpole after the addition of Jason-2. The mean and standard deviation of the differences are given in Table 3 for the different time periods.

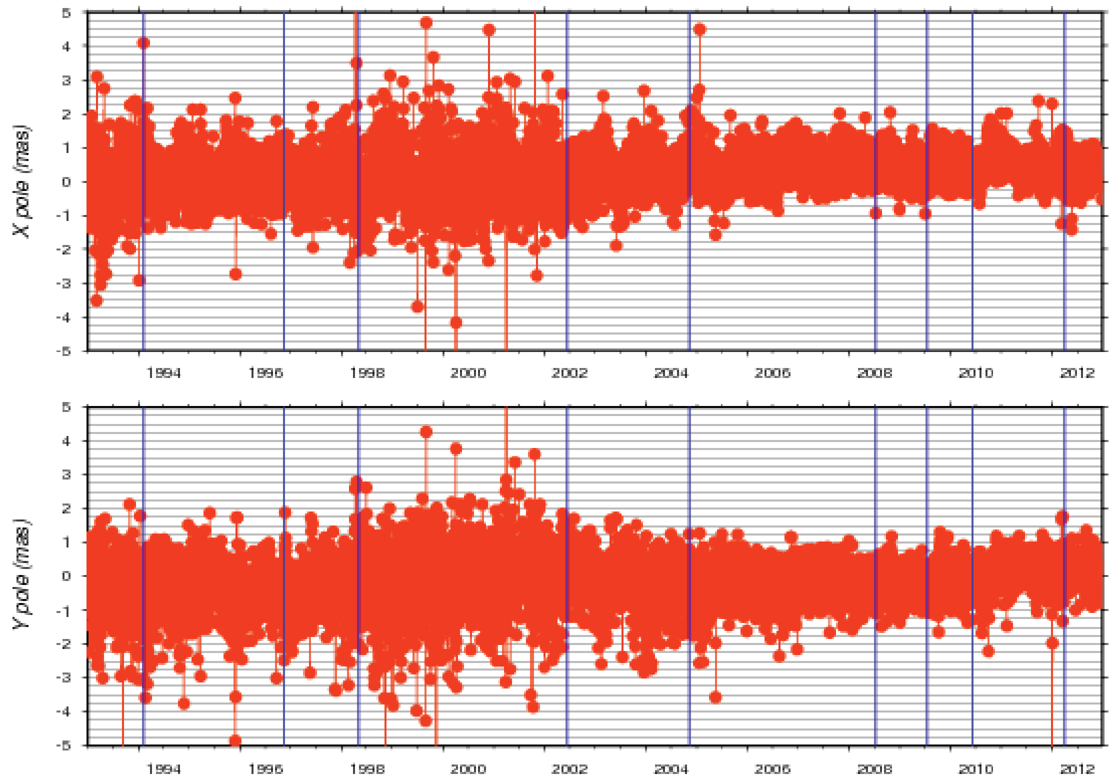

Figure 6 Polar motion daily difference between the gscwd23 combined weekly solution and IERS C04 series. Vertical lines in blue correspond to changes in the DORIS constellation.

This improvement is due after 2008 to the large increase in the amount of data available with the new DGXX receiver onboard Jason-2 (typically 8,000 data points per day for SPOT-5 or Envisat but 17,000 for Jason-2). We note an improvement in the standard deviation of the differences with IERS C04 after the addition each new satellite with a DGXX receiver.

Table 3 Time evolution of polar motion differences between the esawd08 weekly solution and IERS C04 series.

Period	number of DORIS satellites	X pole mean/std (in mas)	Y pole mean/std (in mas)
2000-001 to 2002-160	3	0.292 / 2.609	0.207 / 1.449
2002-167 to 2004-312	5 (+Envisat +SPOT-5)	0.270 / 2.111	-0.177 / 1.009
2004-319 to 2008-195	4 (-TOPEX/Poseidon)	0.197 / 1.958	0.106 / 0.902
2008-202 to 2010-150	5 (+Jason-2)	0.273 / 0.882	0.237 / 0.521
2010-157 to 2011-275	6 (+Cryosat-2)	0.283 / 0.545	0.202 / 0.374
2011-282 to 2012-152	7 (+HY-2A)	0.384 / 0.398	0.292 / 0.343

The improvement in precision due the increase of DORIS data can also be seen when looking at geodetic station positioning. As shown in Figure 7, DORIS station position consistency regularly improves with time, when considering the gscwd21 weekly solution, which is an improved GSFC weekly solution compared to the solution submitted before by this group in view of ITRF2008 (Le Bail et al. (2010)). In Figure 7, vertical bars indicate epochs of changes in the DORIS constellation.

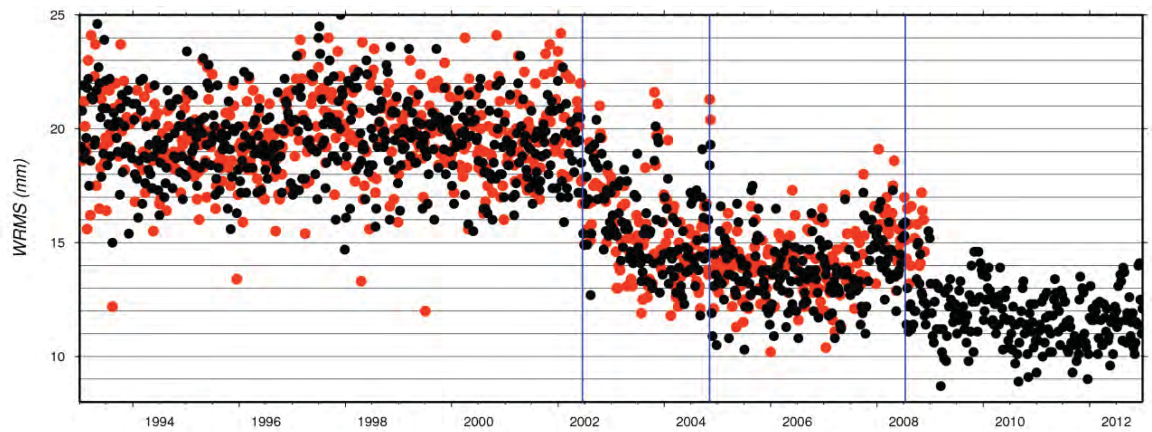

Figure 7 Internal consistency of the gscwd10 (previous solution in red) and gscwd23 solution (new solution in black). 3D WRMS when comparing station positions in 3D with the previous week. Vertical lines in blue correspond to changes in the DORIS constellation.

Some statistics are also provided for these results in Table 4, where the increasing number of available DORIS satellites continuously improves the geodetic results, as discussed before in Willis (2007). Major differences are due to the availability of the new Envisat and SPOT-5 data in mid-2002, the end of TOPEX data in 2004 (which surprisingly seems to improve results at that time) and the availability of the new Jason-2 data in late 2008.

Table 4 Time evolution of DORIS geodetic precision (WRMS) as indicated by the internal consistency of the gscwd10 weekly solution (previous solution) and gscwd23 weekly solution (new solution). Comparison with similar results from previous week.

Period	number of DORIS satellites	WRMS of gscwd10 (in mm)	WRMS of gscwd23 series (in mm)
1993-001 to 2002-173	3	19.71	19.54
2002-174 to 2004-318	5	15.63	15.71
2004-319 to 2008-201	4	14.15	13.79
2008-202 to 2012-365	5		11.77

Other improvements are also under consideration in preparation of ITRF2013, such as the use of antenna phase laws corrections for the Alcatel and Starec antennae, equivalent to the GPS phase center corrections, but only showing an elevation dependency due to the nature of the DORIS transmitting antennae. Possible use of the most recent DORIS data provided by the HY-2A and Saral satellites is also under consideration by different DORIS ACs.

6 Conclusions

In conclusion, the DORIS system should remain operational until 2026, if not 2030. The IDS has started several validation studies in preparation for ITRF2013, involving the current six Analysis Centers and the Combination Center. Satellite-specific and DORIS-data related problems were identified and most of them are now resolved. Improvements in the accuracy of the DORIS-derived geodetic products are expected for the future combined solution, for both the polar motion determination and the station positioning. Such improvements are due to the large increase in DORIS data per station, thanks to the new DGXX receivers on-board the satellites, as

well as improved data processing strategies: a new gravity field including time variable coefficients, satellite physical models or phase center corrections. At the time of writing, all IDS groups are working to refine their data processing scheme in order to be ready in time for the IDS submission to ITRF2013.

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[2]IPGP, Planetologie et Sciences spatiales, Paris, France, willis@ipgp.fr

[3]GSFC, Greenbelt, MD, USA, frank.g.lemoine@nasa.gov

[4]CLS, Toulouse, France, gmoreaux@cls.fr

[5]CLS, Toulouse, France, lsoudarin@cls.fr

[6]CNES, Toulouse, France, pascale.ferrage@cnes.fr

[7]U. Texas, Center for Space Research, Austin, TX, USA, ries@csr.utexas.edu

[8]ESA, Darmstaadt, Germany, michiel.otten@esa.int

[9]IGN, Service de Geodesie et de Nivellement, Saint-Mande, France, jerome.saunier@ign.fr

[10]GSFC, CDDIS, Greenbelt, MD, USA, carey.e.noll@nasa.gov,

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[12]USNO, Washington DC, USA, brian.luzum@usno.navy.mil

Key words : DORIS – International DORIS Service – Terrestrial Reference Frame – Jason-2 – Polar Motion

Abstract. The International DORIS Service (IDS) was created in 2003 under the umbrella of the International Association of Geodesy (IAG) to foster scientific research related to the French DORIS tracking system and to deliver scientific products, mostly related to the International Earth rotation and Reference systems Service (IERS). We first present some general background related to the DORIS system (current and planned satellites, current tracking network and expected evolution) and to the general IDS organization (from Data Centers, Analysis Centers and Combination Center). Then, we discuss some of the steps recently taken to prepare the IDS submission to ITRF2013 (combined weekly time series based on individual solutions from several Analysis Centers). In particular, recent results obtained from the Analysis Centers and the Combination Center show that improvements can still be made when updating physical models of some DORIS satellites, such as Envisat, Cryosat-2 or Jason-2. The DORIS contribution to ITRF2013 should also benefit from the larger number of ground observations collected by the last generation of DGXX receivers (first instrument being onboard Jason-2 satellite). In particular for polar motion, sub-milliarcsecond accuracy seems now to be achievable. Weekly station positioning internal consistency also seems to be improved with a larger DORIS constellation.

1 Introduction

Following a preliminary Pilot Project (Tavernier et al. (~~,~~2002)), an International DORIS Service (IDS) was created in 2003 to foster international scientific cooperation for geodesy and geophysics (Willis et al. (~~,~~2010)). DORIS is an acronym for Doppler Orbitography and Radiopositioning Integrated by Satellite. The goal of this paper is to present the first steps taken by the IDS groups in preparation for the next ITRF2013, to discuss new DORIS results, future improvements and possible limitations. We will present recent improvements related to the DORIS technique (evolution of the satellite constellation and ground infrastructure). Then, after a brief description of the current IDS organization, we will detail the current IDS plans in preparation for ITRF2013. Finally, we will provide a few examples showing areas where further improvements are still required.

2 DORIS ground and satellite infrastructure

Unlike Global Navigation Satellite Systems (GNSS), the number of DORIS satellites changes with time as the main application of this system is Precise Orbit Determination (POD) for real-time (Jayles et al. (~~,~~2010)) or post-processing applications (Cerri et al. (~~,~~2010);~~,~~ Lemoine et al., (2010)) and not time and positioning on the Earth. As of September 2013, data from five DORIS satellites can be used for geodesy and geophysics through the IDS Data Centers, including the recent Chinese HY-2A satellite and the Indian Saral satellite, both launched for altimetry.

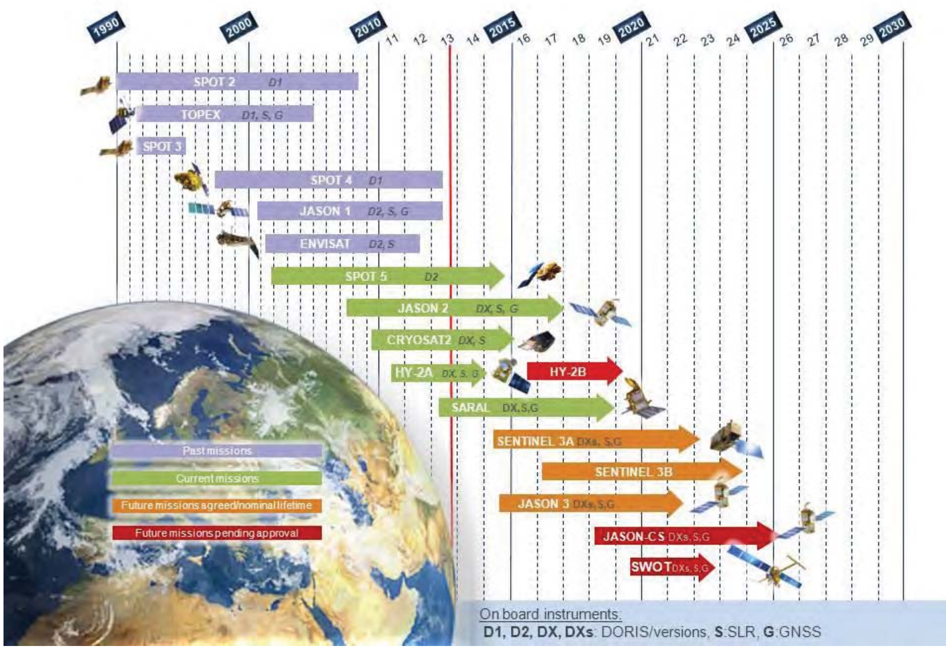

Figure 1 Current DORIS satellite constellation (September 2013)

Figure 1 shows that more DORIS satellites should also be launched in the next few years. According to CNES, the DORIS system could maintain operations at least until 2026 (Ferrage, personal communication), if not 2030. It must also be noted that the most recent DORIS satellites now include onboard DGXX receivers, allowing a more robust tracking of the ground stations, thanks to their new multi-channel technology (Auriol and Tourain, 2010). Up to seven

DORIS ground tracking stations can be tracked simultaneously by each of the new satellites (instead of previously only one for SPOT-2,-3, -4 and TOPEX/Poseidon and later two for SPOT-5, Jason-1, and Envisat).

Since 1993, the DORIS ground tracking network has remained rather stable with time (Fagard, 2006) with 50 to 60 operating stations. As displayed in Figure 2, this network is geographically well distributed and also includes a large number of sites co-located with other space techniques such as Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and GNSS, contributing and enhancing the development of the ITRF and its applications (Altamimi et al., (2005); Altamimi and Collilieux (~~,~~ 2010)). For the ground equipment, only two types of DORIS antennae have been used. The Alcatel antennae, used initially, have now been all replaced with the Starec generation.

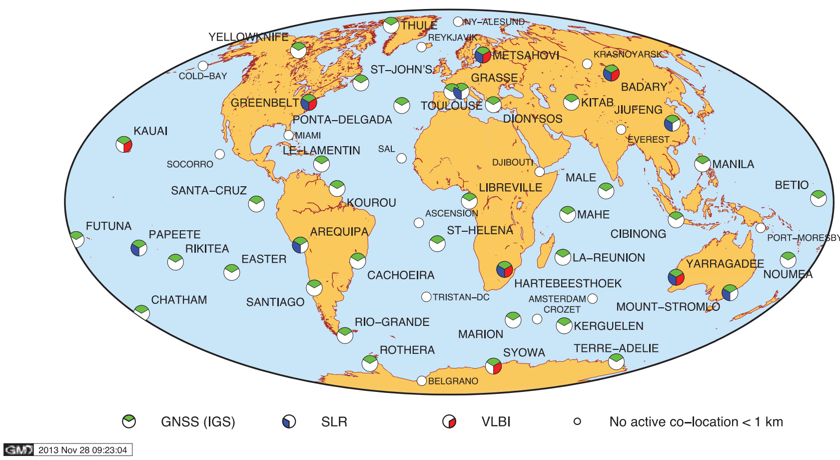

Figure 2 Current DORIS tracking network and co-location with other geodetic space techniques (November 2013)

More information regarding these stations, such as the description of co-located instruments, for instance geodetic technique instruments but also absolute gravity and tide gauges, can be found in the electronic supplement of Willis et al. (~~,~~ 2010) and also online through a GoogleEarth application developed by the IDS Central Bureau at http://ids-doris.org/network/googleearth.html).

3 International DORIS Service – Current structure and products

Like the other IAG Services, the IDS is organized as follows: several Analysis Centers (see Table 1) generating different scientific products, a Combination Center (at CLS) combining these results, two Data Centers (at NASA/CDDIS and at IGN) archiving the different DORIS data and products (Noll, 2010), a Central Bureau (CNES/CLS/IGN) providing day-to-day

operations and in particular maintaining the IDS Web site (http://ids-doris.org), and a Governing Board giving long-term directions and ensuring regular contact with other entities such as the IAG, Global Geodetic Observing System (GGOS) and the IERS.

Table 1 Past and current IDS analysis centers

Analysis Center	Acronym	Country	Software package	Current status
ESA/ESOC	ESA	Germany	NAPEOS	active
Geosciences Australia	GAU	Australia	GEODYN	past
GeoForschungsZentrum	GFZ	Germany	EPOS	proposed
NASA/GSFC	GSC	USA	GEODYN	active
Geodetic Observatory of Pecny	GOP	Czech Rep.	Bernese	active
IGN	IGN	France	GIPSY-OASIS	active
INASAN	INA	Russia	GIPSY-OASIS	active
CNES/CLS	LCA	France	GINS/DYNAMO	active

As of September 2013, six Analysis Centers (using 5 different software packages) plan to participate in the IDS combination, providing weekly time series of station positions with full covariance information in SINEX format with either normal equations or as loosely constrained solutions with full covariance information. These six individual contributions will be merged by the IDS Combination Center (Valette et al. (~~,~~2010)), providing a unique DORIS time series, which would then be used by the ITRF Combination Centers (Altamimi et al. (~~,~~2011); Seitz et al., (2012)) to realize the future ITRF2013 solution, in conjunction with similar combinations provided by VLBI, SLR and GNSS.

Table 2 displays the different products generated for the IDS by the Analysis Centers (ACs) and/or by the Combination Center.

Table 2 List of current IDS products (September 2013)

Product	format	Frequency delivery	from Analysis Center	from Combination Center
station coordinates	SINEX	weekly	√	√
Earth Orientation Parameters	IDS	weekly	√	√
geocenter motion	IDS	weekly	√	√
orbits	sp3	daily	√	
reference frame	SINEX	yearly	√	

DORIS can also provide other types of scientific results such as precise orbit determination, as discussed before, as well as tropospheric Zenith Total Delays (ZTDs), as recently shown by Bock et al. (2010) and Stepanek et al. (2010).

4 Plans towards ITRF2013

Almost all Analysis Centers plan to use the most recent EIGEN-6S2 gravity field (Förste et al. ~~,~~ (2012); Rudenko et al. (~~,~~submitted)), which augments a new static field with annual fits to time variable gravity coefficients derived from the GRACE mission (Tapley et al. (~~,~~2004)) or from SLR data outside this period of time (Cerri et al. (~~,~~2013)). As proposed for ITRF2008, solar radiation reflectivity scaling factors or improved macromodels will be used for all DORIS satellites when modeling the radiation pressure accelerations (Gobinddass et al. (~~,~~2009); Le Bail

et al. (~~,~~2010)) and an atmospheric drag parameter will be estimated more frequently (every 30 minutes to 8 hours, depending on the satellite altitude and on the daily values of the geomagnetic indices) (Gobinddass et al. (~~,~~2010); Stepanek et al. (~~,~~2010)). The implementation of the satellite attitude laws in POD software has been re-verified by some analysis centers. The periodic changes in the solar array pitch of the SPOT-5 satellite after 22 January 2008, as previously detected in Gobinddass et al. (~~,~~2009) are also now explicitly accounted for, following new information available from CNES (ftp://ftp.ids-doris.org/pub/ids/satellites/DORISSatelliteModels.pdf). Problems related to some DORIS data sets were also recently corrected: timetagging for Envisat, South Atlantic Anomaly (SAA) effects on SPOT-5 oscillator (Stepanek et al. (~~,~~2013)).

Some problems that were not previously detected and which affected the ITRF2008 solutions are now solved. As an example, Figure 3 shows that some DORIS Analysis Centers did not handle properly the frequency offsets between the actual frequency of the transmitted signal at 2GHz by the beacons and its nominal value (2.03625 GHZ). The error, which resulted from using standard station frequency value, was corrected by modifying the partial derivatives for bias estimation. This error mostly affected the estimated station height, introducing discontinuities in some of the AC solutions, which were consequently propagated into the combined solution as well as in the ITRF2008.

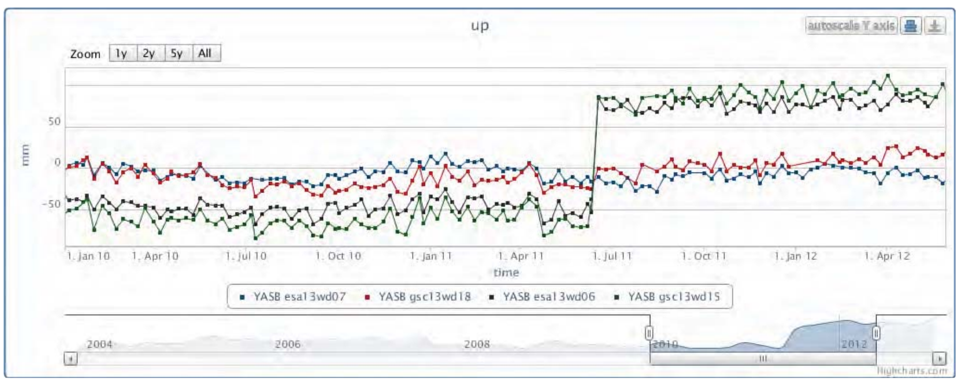

Figure 3 Time series of weekly station height determination for Yarragadee station: two solutions used for ITRF2008 and their current preliminary solutions for ITRF2013 (using Plottool). Previous esa13wd07 (in green) and gscwd06 (in black) show a clear discontinuity, coming from a data processing artifact.

As shown in Figure 3, the new solutions do not display any discontinuity related to a change in ground oscillator frequency, while the previous solutions used in preparation of ITRF2008 were affected by a large discontinuity. This problem is now solved and consequently should not affect the IDS combination, nor the future ITRF2013 solution.

5 Early results towards ITRF2013

In preparation for ITRF2013, intensive comparisons were made by all Analysis Groups under the direction of the Analysis Coordinator (Frank Lemoine). Some of the orbit comparisons for all satellites were made and some of them demonstrated deficiencies for some of the Analysis Centers. In preparation for ITRF2013, more detailed tests were also performed for some of the DORIS orbit parameters, especially the once-per-revolution (OPR) empirical accelerations, usually estimated once per day for each satellite. The magnitude of the empirical accelerations reflects the quality of the non-conservative force modeling and can be used to identify problems

in the satellite force models used in the data processing. This is important for the quality of the DORIS results as previous studies demonstrated that errors in non-conservative force models can map into errors in the geodetic results such as TZ-geocenter or the height of high latitude stations. These errors can appear with strong signals at the satellite draconitic (solar beta-prime) periods, when large values of the OPR try to mitigate deficiencies in the solar radiation pressure modeling (Willis et al. (~~,~~2006)). The estimation of a cross-track empirical once-per revolution (OPR) acceleration has been a standard practice in POD analysis for altimeter satellites or by DORIS analysis centers (e.g. Le Bail et al. (~~,~~2010); Lemoine et al. (~~,~~2010); Zelensky et al. (~~,~~2010); Cerri et al. (~~,~~2010)). However, this parameter is not always well-determined and appears to weaken the DORIS coordinate solutions in certain satellites. For this reason, some ACs decided to avoid estimating the cross-track OPR as was the practice for all previous ITRF solutions (including ITRF2008).

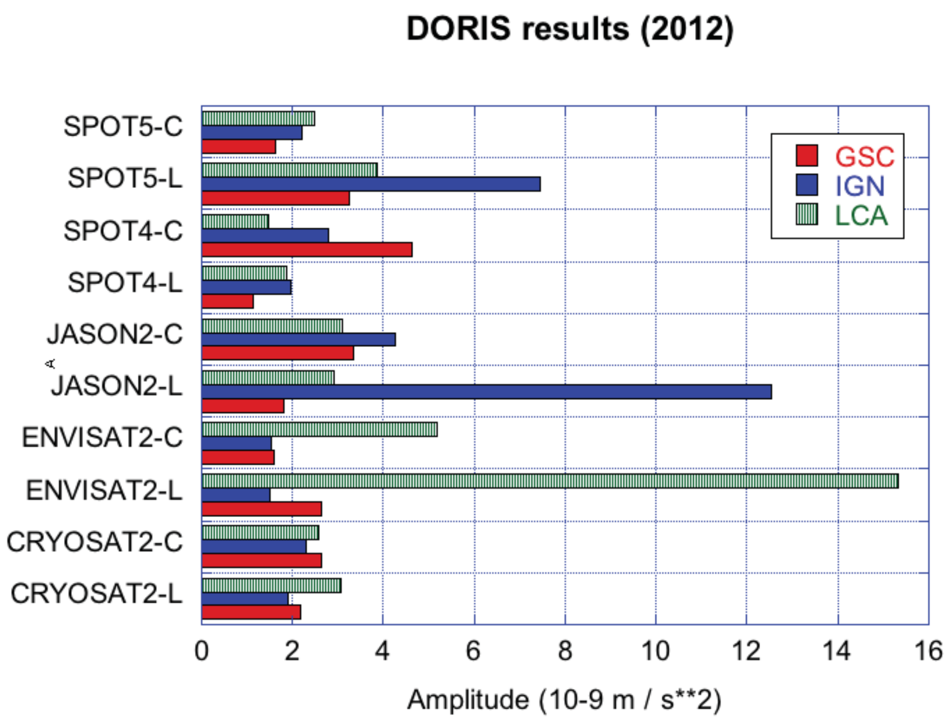

Figure 4 RMS of DORIS empirical parameters (once-per-revolution) estimated by satellite (in 2012), cross-track (C), and along-track (L).

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Figure 4 summarizes for 2012 the RMS daily amplitude of the along-track and cross-track accelerations for the DORIS satellites processed by the GSC, IGN, and LCA analysis centers. Some modeling problems are still evident in these statistics: e.g., Envisat for LCA, Jason-2 and SPOT-5 for IGN. It can also be seen that the groups that perform better for these satellites may not perform as well for other satellites. Systematic inter-comparisons of results between groups and open discussions should help to resolve such disparities in performance, allowing all groups to provide the best possible results by the end of this verification phase. Early discussions already allowed some groups to identify and to resolve modeling issues for some satellites.

However, other problems are also common to all groups and may be more difficult to solve. For example, Figure 5 shows that a significant jump can be seen in the DORIS results for Tz translation (from the combined solution) when the new Jason-2 data are introduced. A more detailed analysis showed that all groups observe this feature. This apparent discontinuity in Tz has two origins: i) From the end of the availability of DORIS on TOPEX/Poseidon (in November 2004), as Jason-1 was not included in the weekly solutions due to the~~its~~ sensibility of its~~the~~ Ultra Stable Oscillator (USO) to radiation in the SAA region, Jason-2 was the first satellite with a different orbit plane (66° of inclination compared to 98° for the rest of the DORIS constellation at that time); ii) Jason-2 is the first satellite with the so-called DORIS receiver on board that can track up to seven beacons simultaneously (compared to one for SPOT-2-4 and two for SPOT-5 and Envisat). We interpret this change – a better centering of the Tz parameter of the combination solution -- as beneficial, and thus it motivated the DORIS ACs to consider the inclusion of Jason-1 from November 2004 to July 2008. The Jason-1 DORIS data will be processed with the SAA data correction provided by Lemoine and Capdeville (2006), where the Jason-1 station data most affected by the SAA will be down-weighted or excluded from the combination.

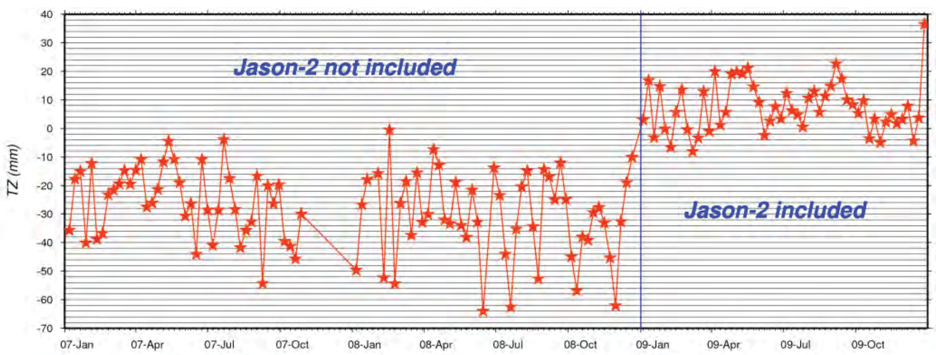

Figure 5 TZ-geocenter weekly comparisons between the preliminary IDS combined weekly solution and the ITRF2008. Vertical line in blue corresponds to a change in the DORIS constellation.

We also observe impacts on the Earth orientation parameters such as polar motion, when data from the new DORIS satellites (Jason-2, Cryosat-2, HY-2A) are added to the weekly solutions. We compare in Figure 6 the differences in the computed EOP values with the IERS C04 series (Bizouard and Gambis, 2009). The series was provided by the ESA analysis center and represents a step in the development of that analysis center's contribution to the IDS combination for ITRF2013. The largest EOP discrepancies occur prior to 2002 - before SPOT-5 and Envisat started providing data. A noticeable improvement occurs especially for the Xpole after the addition of Jason-2. The mean and standard deviation of the differences are given in Table 3 for the different time periods.

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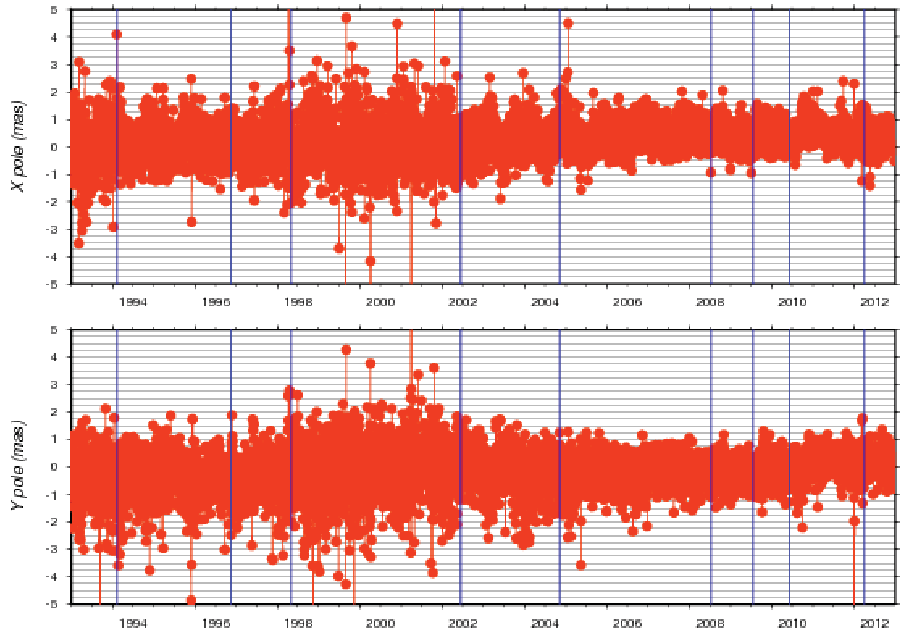

Figure 6 Polar motion daily difference between the gscwd23 combined weekly solution and IERS C04 series. Vertical lines in blue correspond to changes in the DORIS constellation.

This improvement is due after 2008 to the large increase in the amount of data available with the new DGXX receiver onboard Jason-2 (typically 8,000 data points per day for SPOT-5 or Envisat but 17,000 for Jason-2). We note an improvement in the standard deviation of the differences with IERS C04 ~~(Bizouard and Gambis, 2009)~~ after the addition each new satellite with a DGXX receiver.

Table 3 Time evolution of polar motion differences between the esawd08 weekly solution and IERS C04 series.

Period	number of DORIS satellites	X pole mean/std (in mas)	Y pole mean/std (in mas)
2000-001 to 2002-160	3	0.292 / 2.609	0.207 / 1.449
2002-167 to 2004-312	5 (+Envisat +SPOT-5)	0.270 / 2.111	-0.177 / 1.009
2004-319 to 2008-195	4 (-TOPEX/Poseidon)	0.197 / 1.958	0.106 / 0.902
2008-202 to 2010-150	5 (+Jason-2)	0.273 / 0.882	0.237 / 0.521
2010-157 to 2011-275	6 (+Cryosat-2)	0.283 / 0.545	0.202 / 0.374
2011-282 to 2012-152	7 (+HY-2A)	0.384 / 0.398	0.292 / 0.343

The improvement in precision due the increase of DORIS data can also be seen when looking at geodetic station positioning. As shown in Figure 7, DORIS station position consistency regularly improves with time, when considering the gscwd21 weekly solution, which is an improved GSFC weekly solution compared to the solution submitted before by this group in view of

ITRF2008 (Le Bail et al. (, 2010)). In Figure 7, vertical bars indicate epochs of changes in the DORIS constellation.

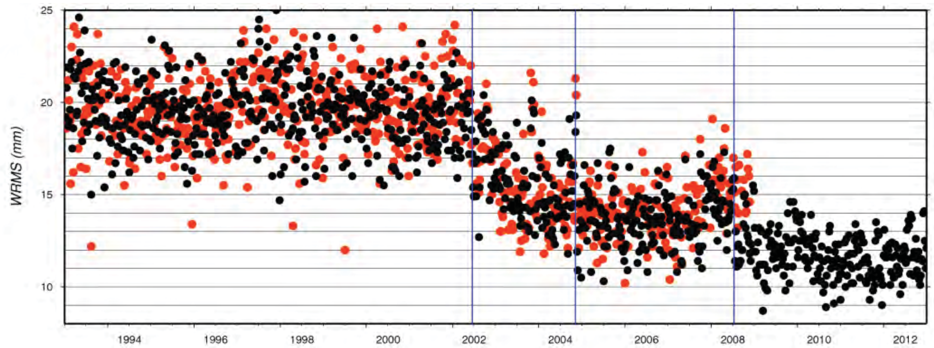

Figure 7 Internal consistency of the gscwd10 (previous solution in red) and gscwd23 solution (new solution in black). 3D WRMS when comparing station positions in 3D with the previous week. Vertical lines in blue correspond to changes in the DORIS constellation.

Some statistics are also provided for these results in Table 4, where the increasing number of available DORIS satellites continuously improves the geodetic results, as discussed before in Willis (2007). Major differences are due to the availability of the new Envisat and SPOT-5 data in mid-2002, the end of TOPEX data in 2004 (which surprisingly seems to improve results at that time) and the availability of the new Jason-2 data in late 2008.

Table 4 Time evolution of DORIS geodetic precision (WRMS) as indicated by the internal consistency of the gscwd10 weekly solution (previous solution) and gscwd23 weekly solution (new solution). Comparison with similar results from previous week.

Period	number of DORIS satellites	WRMS of gscwd10 (in mm)	WRMS of gscwd23 series (in mm)
1993-001 to 2002-173	3	19.71	19.54
2002-174 to 2004-318	5	15.63	15.71
2004-319 to 2008-201	4	14.15	13.79
2008-202 to 2012-365	5		11.77

Other improvements are also under consideration in preparation of ITRF2013, such as the use of antenna phase laws corrections for the Alcatel and Starec antennae, equivalent to the GPS phase center corrections, but only showing an elevation dependency due to the nature of the DORIS transmitting antennae. Possible use of the most recent DORIS data provided by the HY-2A and Saral satellites is also under consideration by different DORIS ACs.

6 Conclusions

In conclusion, the DORIS system should remain operational until 2026, if not 2030. The IDS has started several validation studies in preparation for ITRF2013, involving the current six Analysis Centers and the Combination Center. Satellite-specific and DORIS-data related problems were identified and most of them are now resolved. Improvements in the accuracy of the DORIS-derived geodetic products are expected for the future combined solution, for both the polar

motion determination and the station positioning. Such improvements are due to the large increase in DORIS data per station, thanks to the new DGXX receivers on-board the satellites, as well as improved data processing strategies: a new gravity field including time variable coefficients, satellite physical models or phase center corrections. At the time of ~~the~~ writing, all IDS groups are working to refine their data processing scheme in order to be ready in time for the IDS submission to ITRF2013.

Acknowledgements

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Figure 1: DORIS satellite constellation
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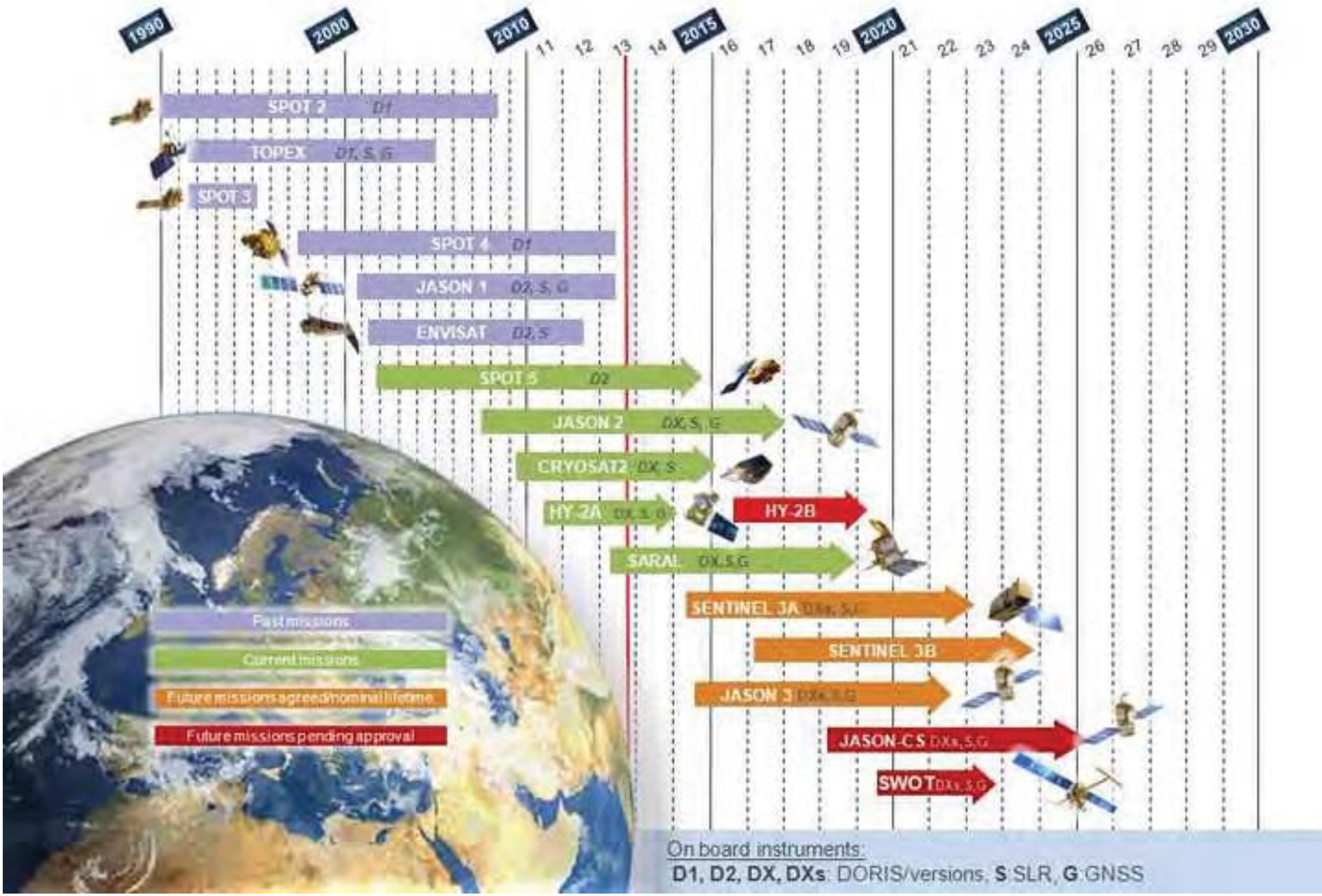

Figure 2: tracking network

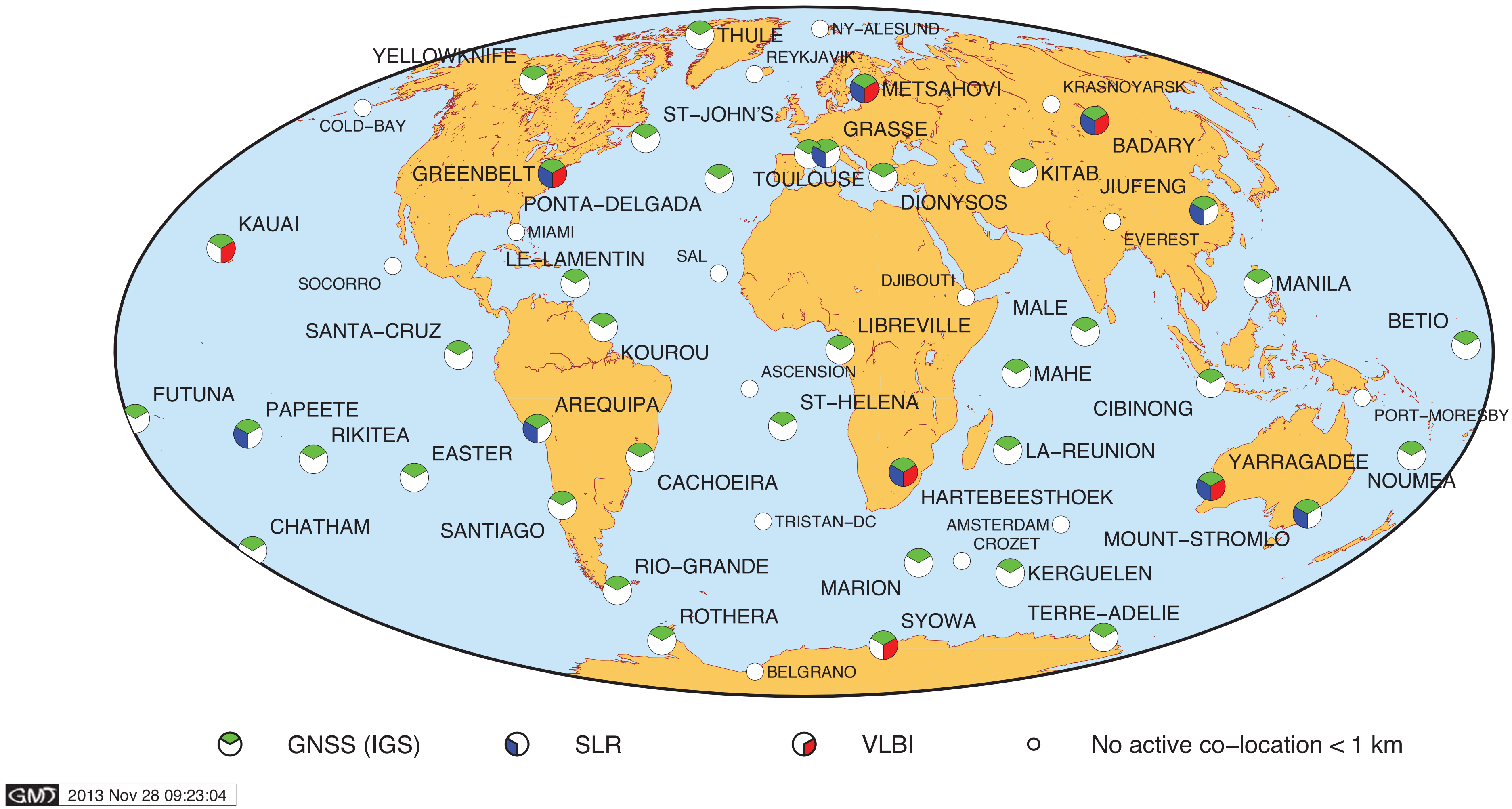

Figure 3: jumps in vertical positions
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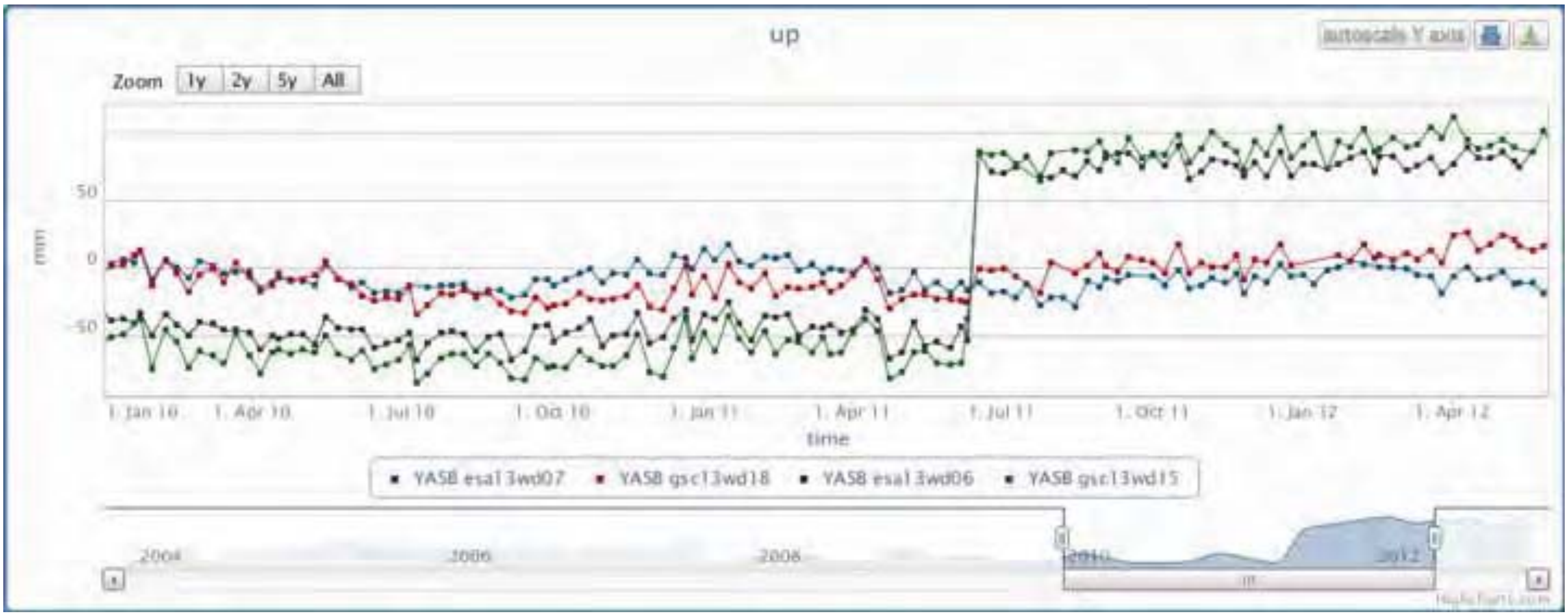

Figure 4: empirical accelerations

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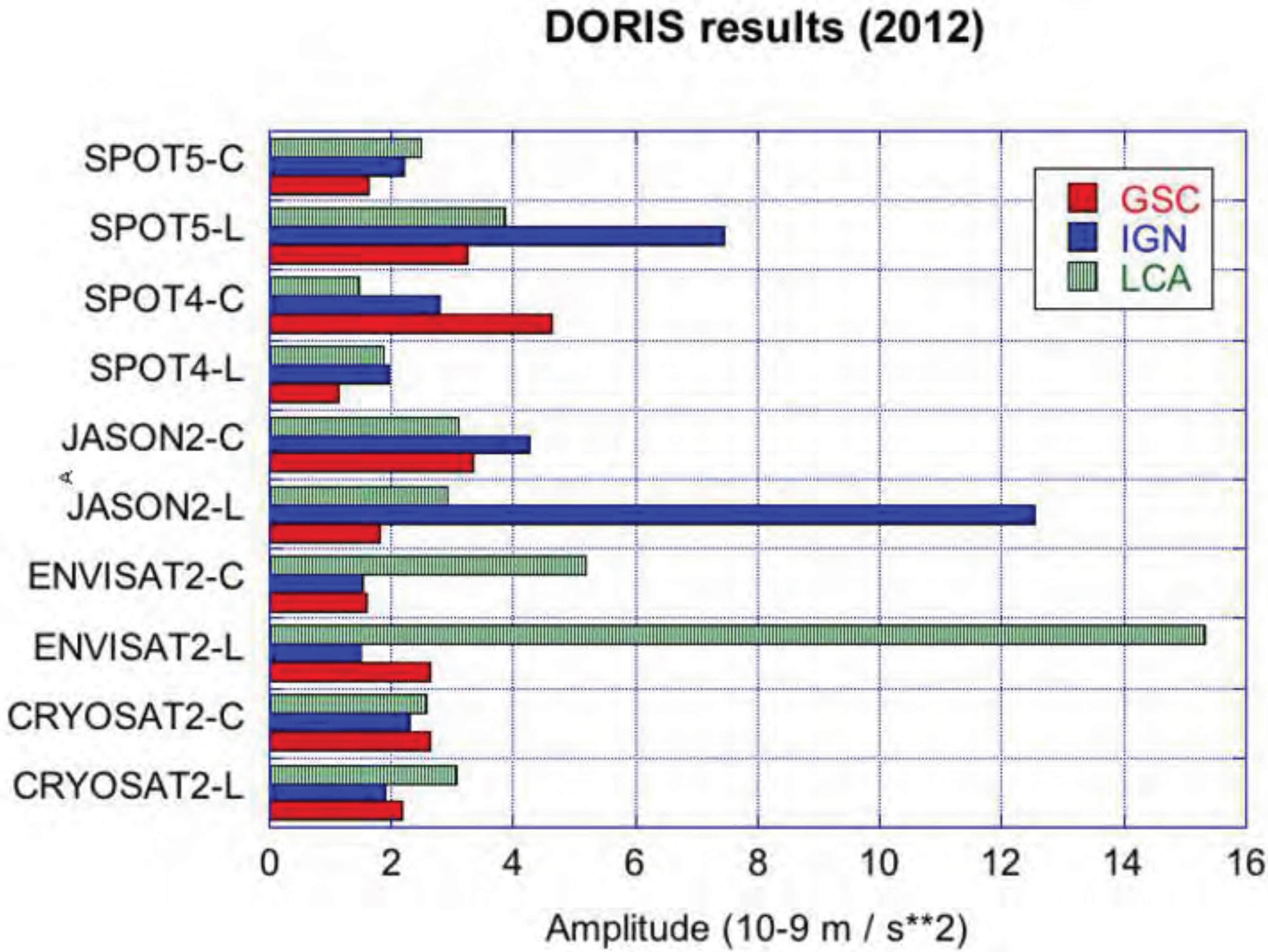

Figure 5: TZ geocenter
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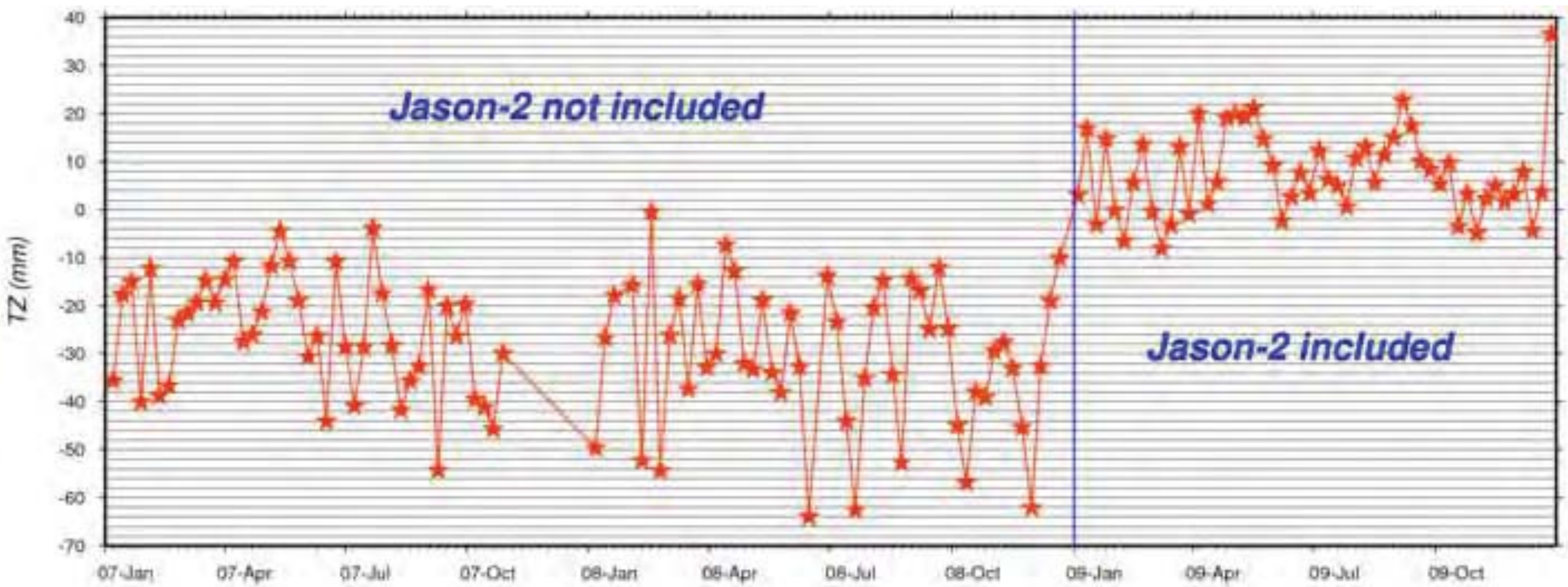

Figure 6: EOP weekly solution - GSC

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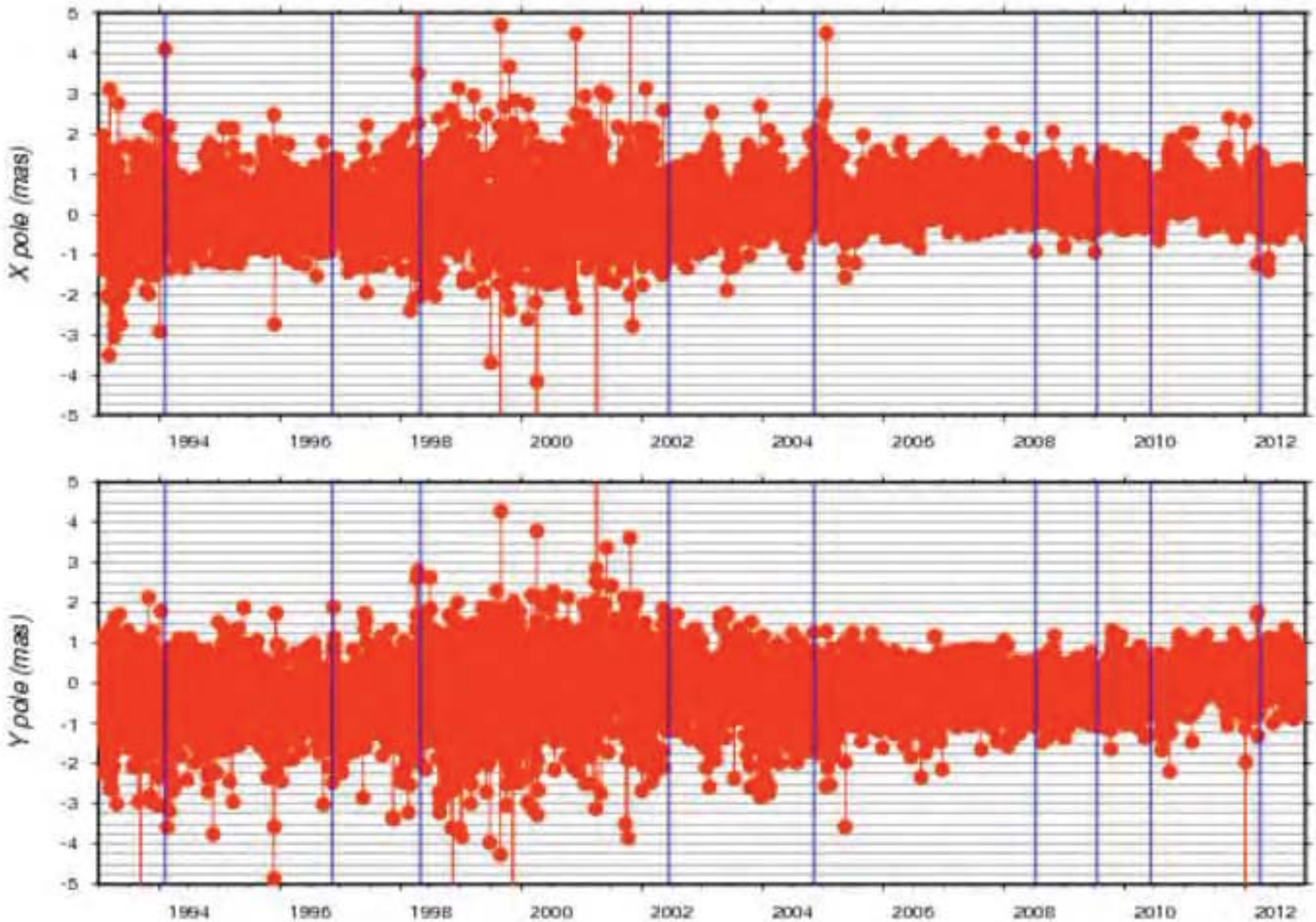

Figure 7: WRMS gscwd10 and 23 weekly solution
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